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AMS Tracker Thermal Control Subsystem

**TTCS Liquid line health
heater calculations**

AMSTR-NLR-TN-061
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Document change log

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-	All	Initial issue



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Summary

This document first describes TTCS condenser liquid line health heater design. Then the design rationale is presented.

The focus is on the heater design calculations showing the maximum temperatures of the pressure lines, heater wire and the nearby carbon fibre rod.



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1 Scope of the document

This document focuses on the wire heater design and design calculations. The condenser design is not part of this document

2 References documents

RD-1	Title	Number
RD-1		



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3 Introduction and description

The objective of the TTCS liquid line heaters is to defrost the TTCS CO₂ condenser lines after an AMS complete power down. The TTCS liquid line heaters are connected to the TTCE and operate at 28 V.

Important remark: The liquid line heaters should be switched on before the 120 V defrost heaters of the Tracker radiators itself (see section Error! Reference source not found.). The liquid lines need to be unfrozen before the condenser section starts to be defrosted. This in order to avoid high pressures in the condenser sections. Safety is looked after by the radiator heater thermostats so it is not a safety issue but a matter of common sense not to stress the condenser lines if not needed.

3.1.1 TTCS liquid line health heater locations

The TTCS liquid line heaters are located near both the RAM and WAKE Tracker radiators. The heaters location is shown in yellow in Figure 3-1. The heaters are connected to the TTCS primary and secondary condensers tubing running from the USS Upper Vacuum Case joints to the Tracker radiator condensers. A total of four (4) condensers are present. The Primary condensers are located at the Port side of AMS Tracker radiators and the Secondary condensers are located at the Starboard side of AMS.

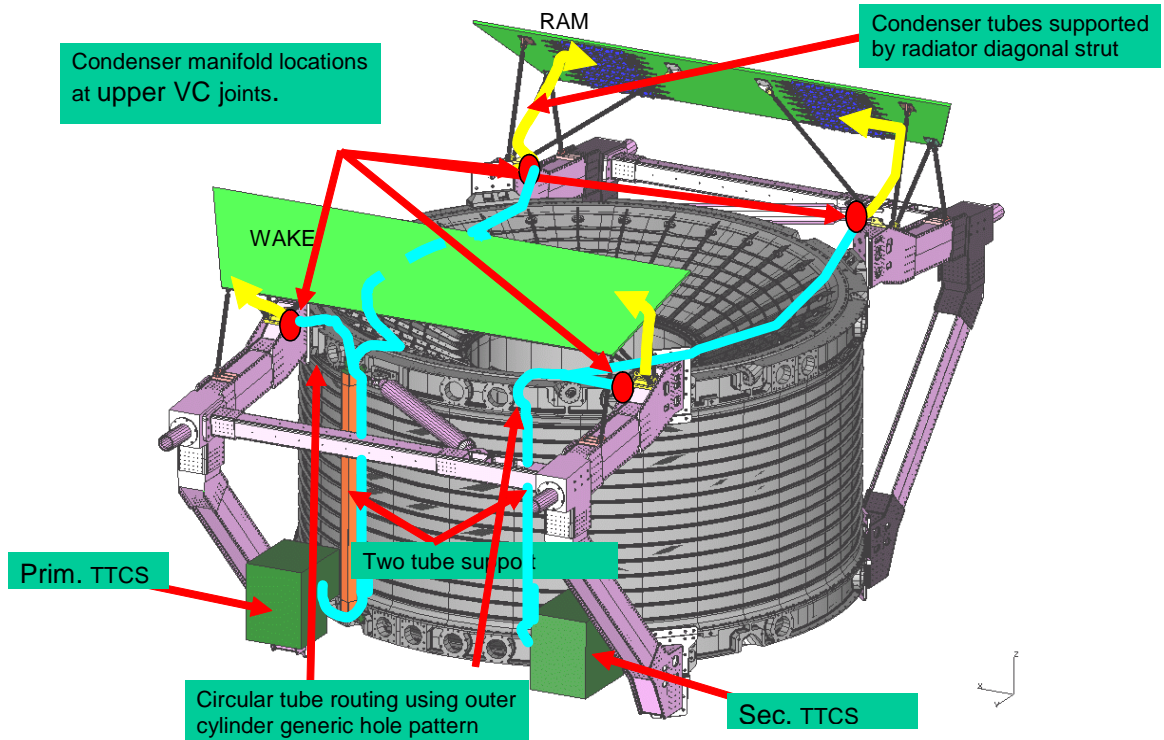


Figure 3-1: Location of the TTCS liquid line heaters (yellow)

The condenser tubing for each of the 4 condensers consists of 14 parallel Inconel tubes (7 inlet and 7 exit tubes). This is shown in Figure 3-2. Two (2) heaters are wrapped around 14 parallel condenser tubes (Figure 3-2). One additional heater is located at the inlet/outlet of the condenser plate to cover the heat leak to the condenser.

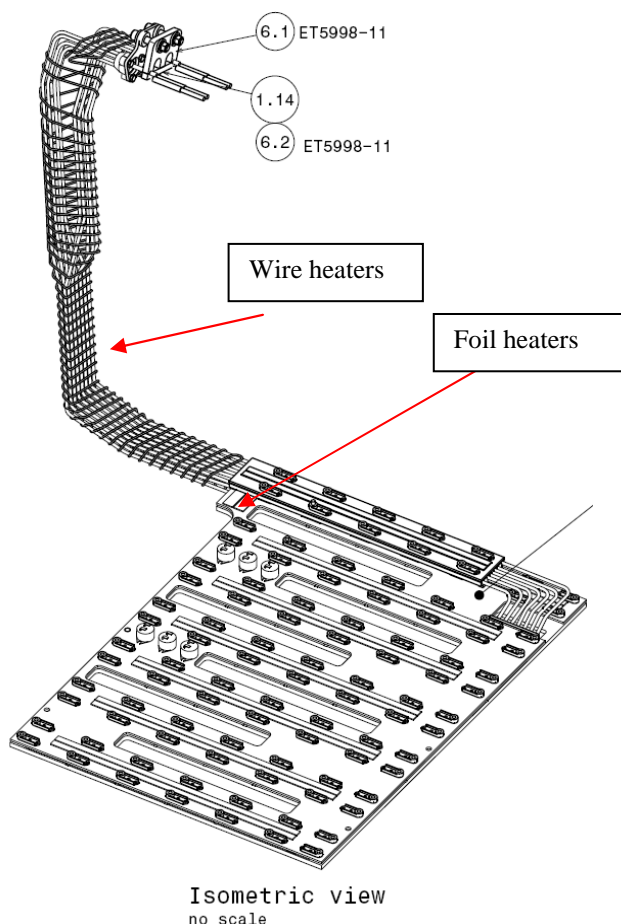
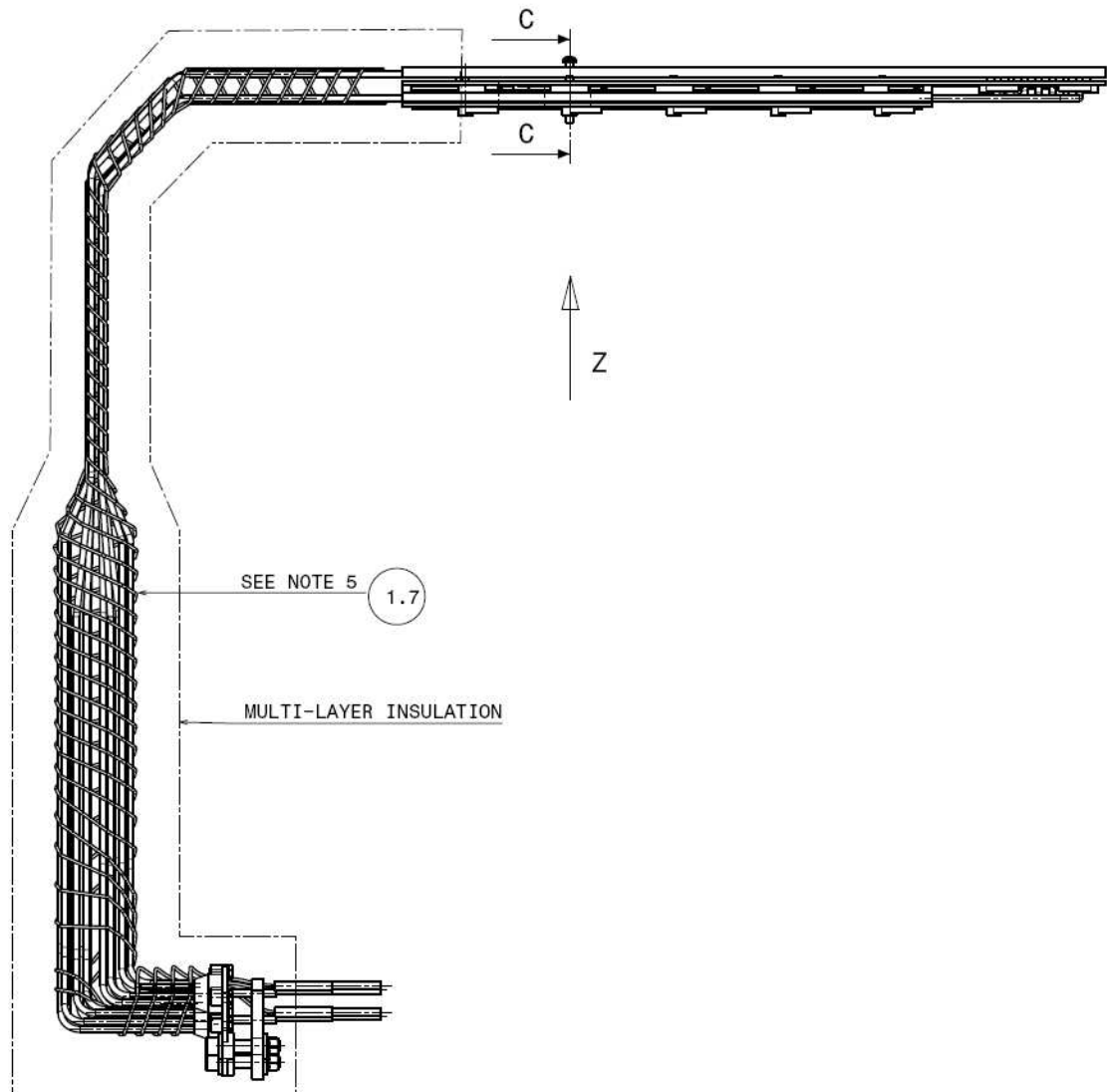


Figure 3-2: TTCS liquid line heater design Primary Wake and Secondary RAM

The heaters are not rigidly attached to the condenser lines but wrapped around. The heater is used to heat the volume including the condenser tubes. Therefore Multi Layer Insulation (MLI) is placed around the capillary tubes. In Figure 3-3 a schematic drawing of the layout is seen. Around the condenser tube bundles two wire heaters are wrapped. One powered by TTCE-A and one by TTCE-B.



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Figure 3-3: MLI heater insulation of the Primary wake and Secondary RAM condenser

The dimensions of the liquid capillary lines are: $D_{in} = 1.0 \text{ mm}$, $D_{out} = 3.15 \text{ mm}$, $L = 0.70 \text{ m}$ inlet and $L = 0.70 \text{ m}$ outlet.

The Minco Foil Heater on the condenser plate is placed in series with the wire heater wrapped around the condenser lines. The heater is located entrance of the capillary liquid lines into the condenser. This is done to compensate the heat leak from the liquid lines into the cold condenser at freezing. The location of the foil heater is seen in the figure above and in more detail below.

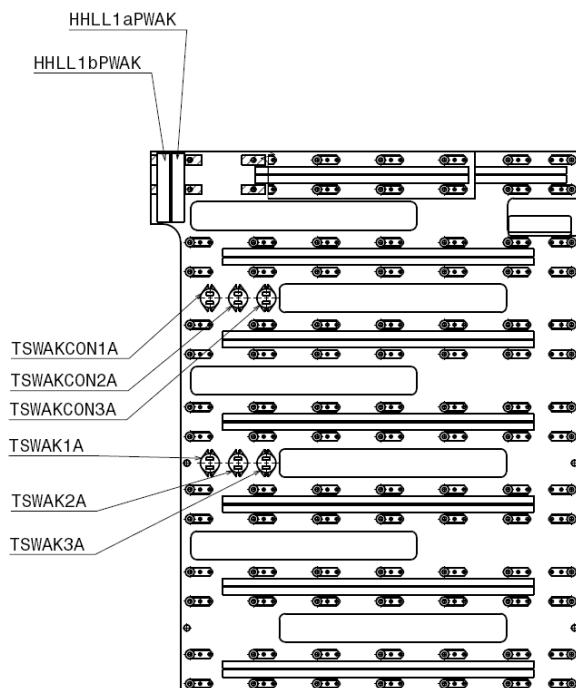


Figure 3-4: Location of the additional TTCS liquid line heater.

The heaters wrapped onto the capillary liquid such that both the feed and return lines terminal blocks are located near the manifold. This is achieved by double folding the wire heaters before wrapping it around the capillary liquid lines; this is seen in Figure 3-5.

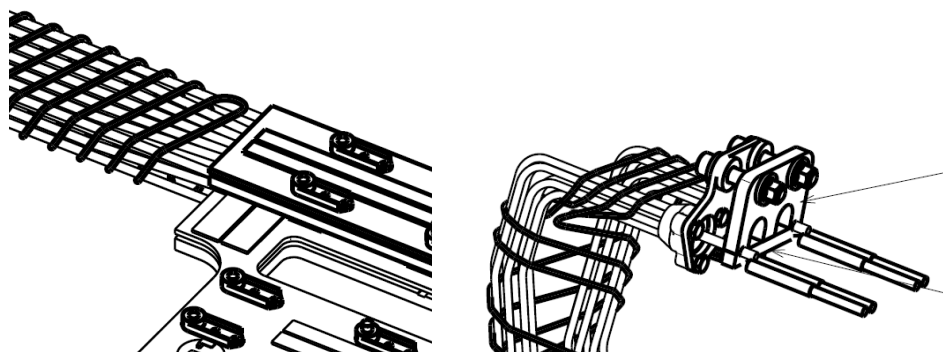


Figure 3-5: Heater assembly on capillary liquid lines (details).

3.1.2 Liquid line heaters electronic lay-out

The lay-out of the electronics is shown in Figure 3-6 to Figure 3-9.

All four condensers have the same heater lay-out and each are individually connected to the TTCE-A and TTCE-B. It is proposed to have only one on/off control for all liquid line heaters.

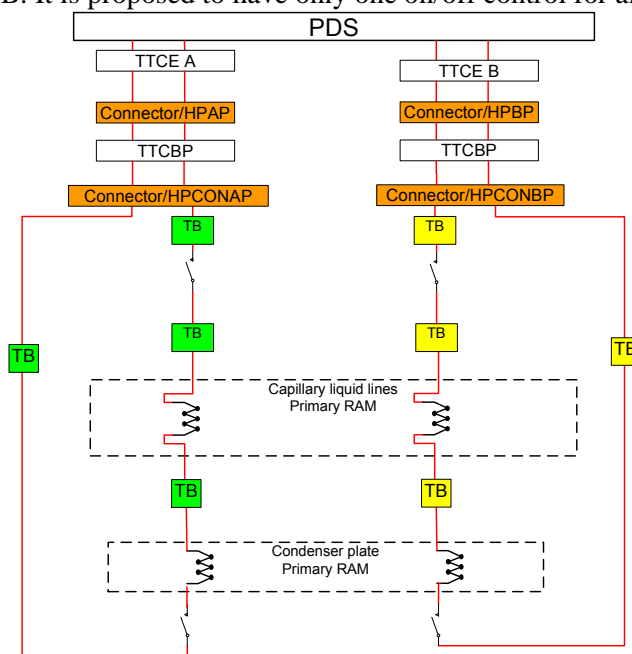


Figure 3-6: TTCS RAM Liquid line heaters schematic primary condenser

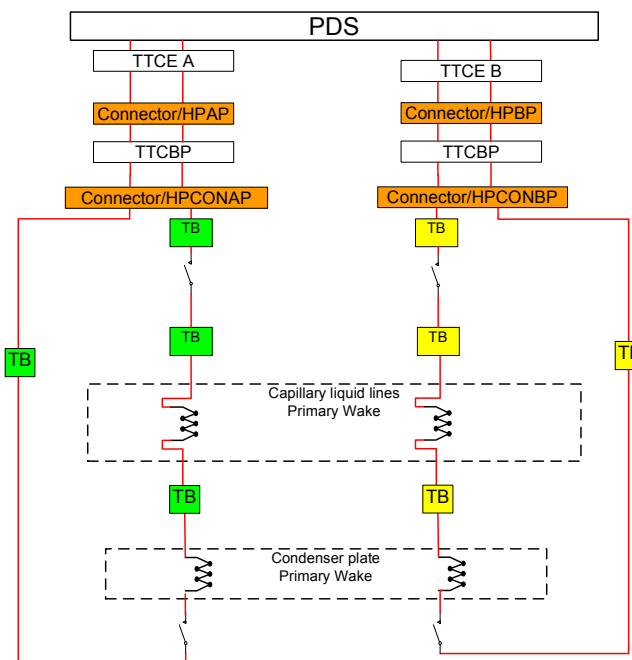


Figure 3-7: TTCS Wake Liquid line heaters schematic primary condenser

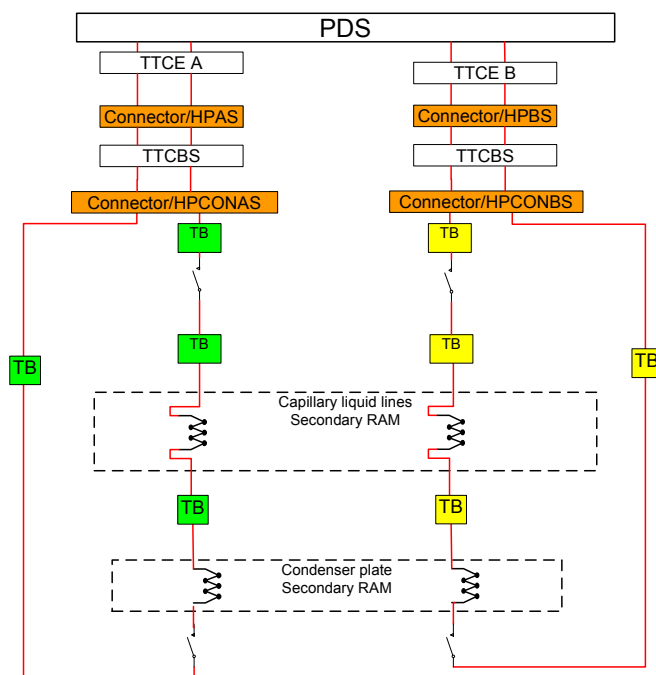


Figure 3-8: TTCS RAM Liquid line heaters schematic secondary condenser

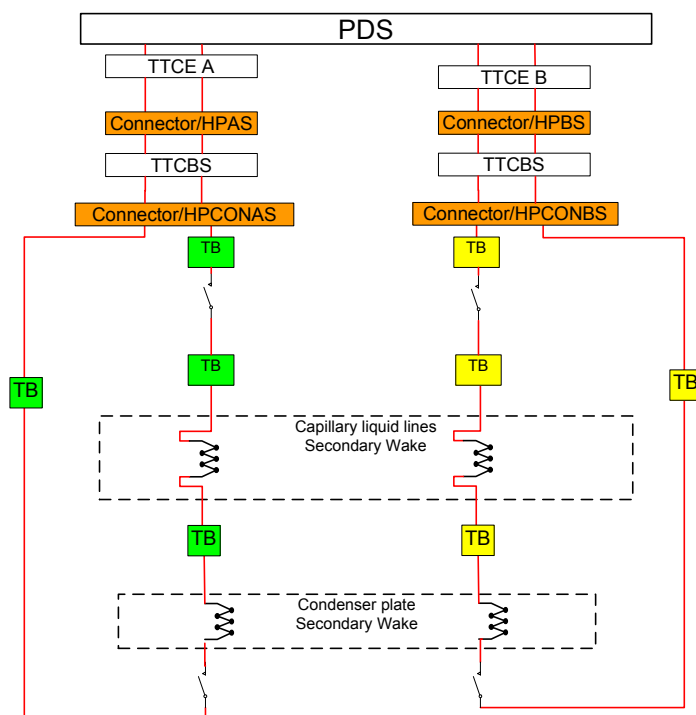


Figure 3-9: TTCS Wake Liquid line heaters schematic secondary condenser

The TTCS liquid line health heaters are labeled per heater section:

- HHLL1aP_RAM

- HHLL1aS_RAM
- HHLL1aP_WAK
- HHLL1aS_WAK
- HHLL1bP_RAM
- HHLL1bS_RAM
- HHLL1bP_WAK
- HHLL1bS_WAK

One section includes 1 wire heater with one foil heater in series as shown in Figure 3-9.
The local connection of the wiring near the condenser manifolds is shown below.

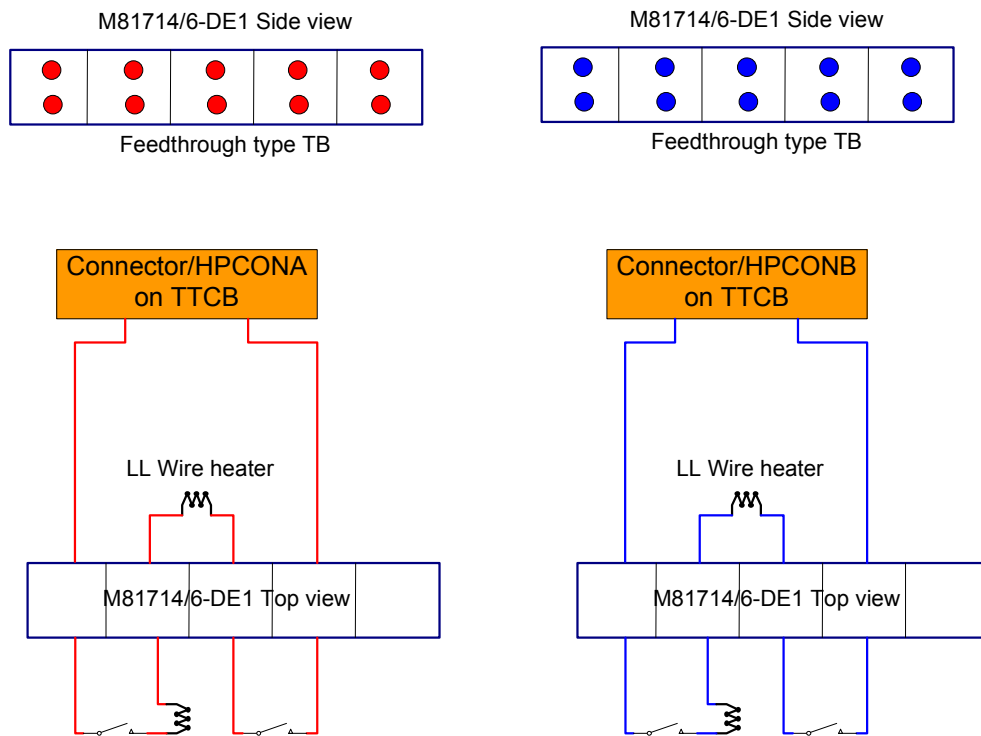


Figure 3-10: Terminal block cabling for foil and wire heater

A is connected to a single separate TB.
B is connected to a single separate TB.

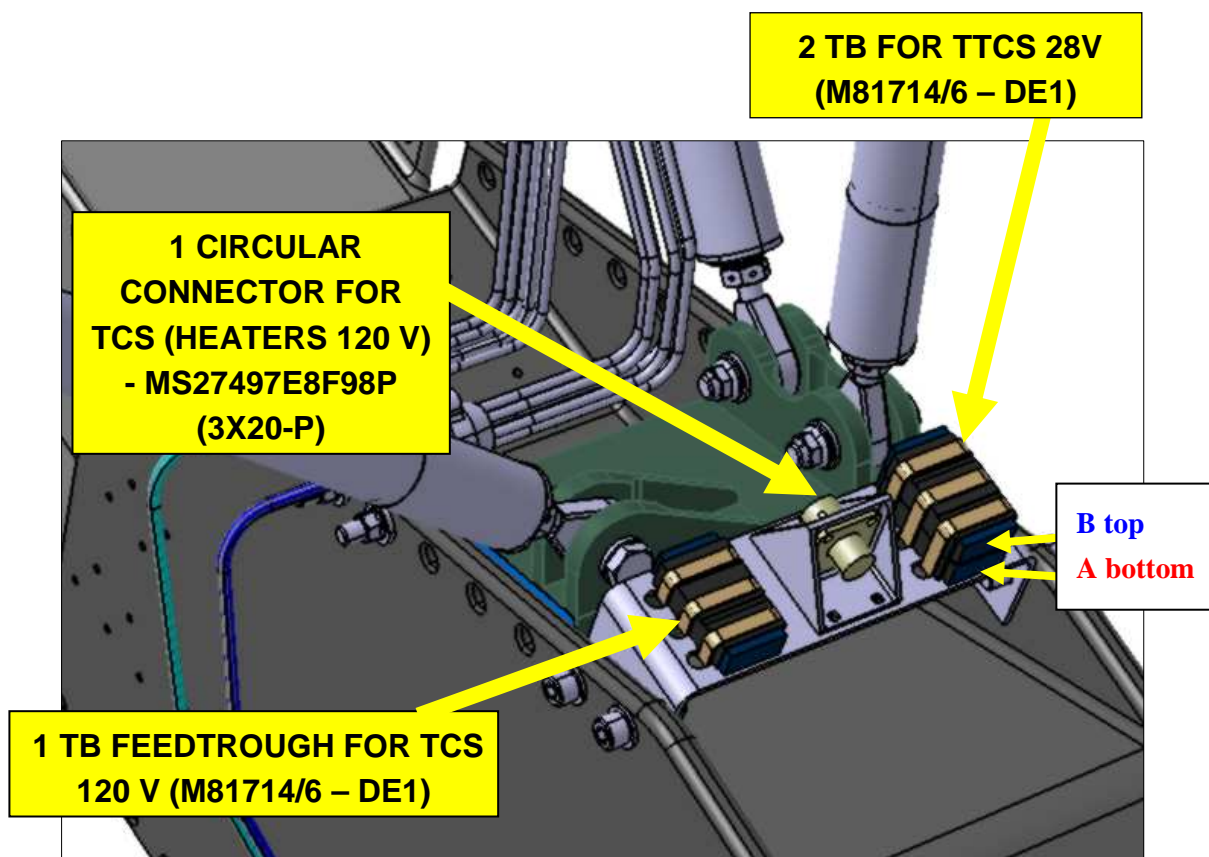


Figure 3-11: Terminal block locations liquid line heaters TB on the right

The mechanical TB location is shared with the terminal block and connector for the 120V heaters (see section **Error! Reference source not found.**). The TB specification is shown in below table in the last row.

3.1.3 Thermostat specifications liquid line wire heaters

The thermostats used on the condenser brackets are the **700 series Thermal Switch** from **Honeywell** having the following characteristics:

- Ambient Temperature Range: -201 °C to +204 °C
- Specified Temp Set point Range: -17.2 °C to 121.1 °C
- Standard set-point Tolerance: ± 2.8 °C
- The 700 series has supporting data at 1 amp 120VDC.

Specification of the dedicated thermostat:

- Honeywell TS701 Part no 701S090A130A
- Opening +54 °C/Closing +32 °C

The thermostats are glued onto the condenser brackets as shown in Figure 3-13 and Figure 3-14.

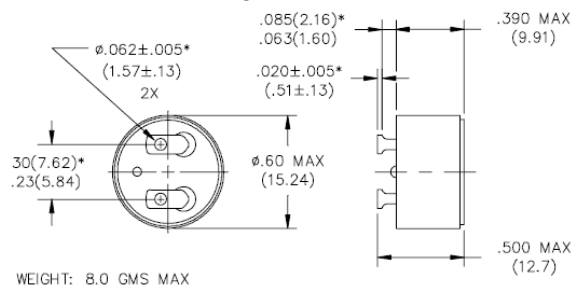


Figure 3-12: Honeywell 700 series layout (dimensions in inches)

3.1.4 Electrical wiring mechanical sketch

In the below 2 pictures the wiring lay-out is shown in a mechanical sketch.

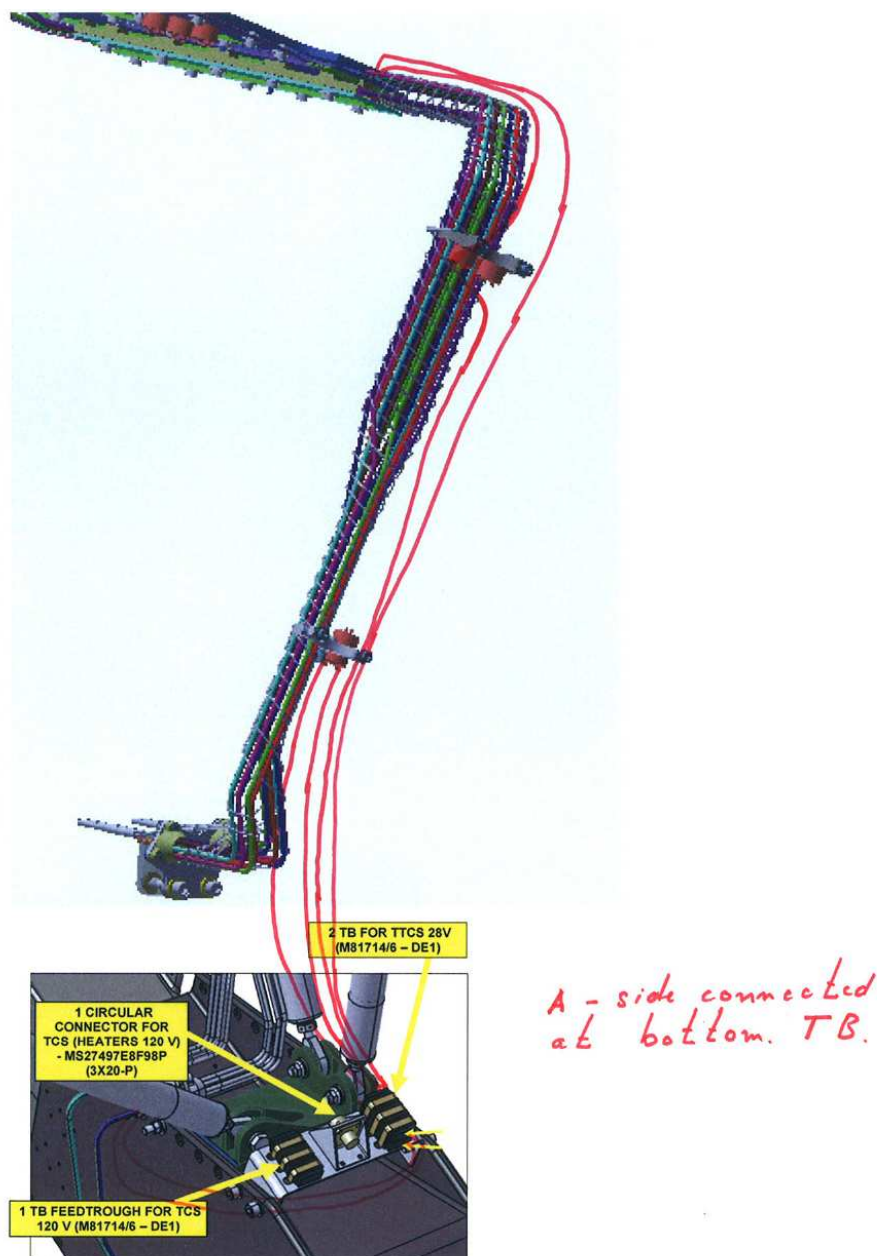
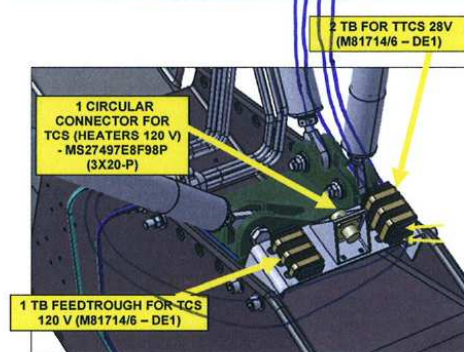
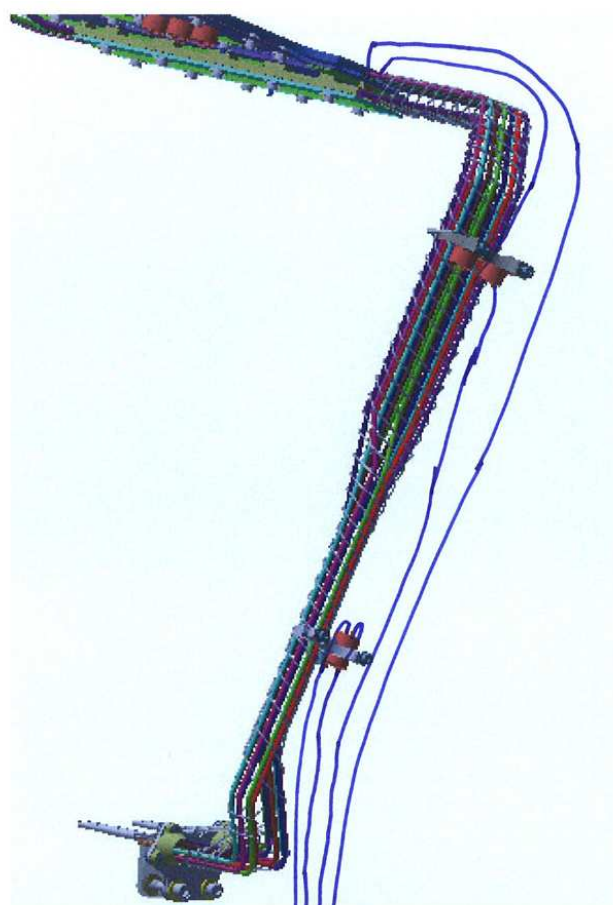


Figure 3-13: Wiring lay-out liquid line wire heaters A-side



B-side attached to top TB

Figure 3-14: Wiring lay-out liquid line wire heaters B-side

This lay-out is similar for all four condensers.



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3.1.5 TTCS liquid line health heater specifications

The liquid line heaters are placed around capillary liquid lines. Each condenser inlet/outlet will be equipped with two redundant wire heaters. The heaters will heat the volume wrapped by MLI and therefore also the condenser lines will be heated.

The wire heaters are chosen such that they deliver 1 Watt per condenser line. The foil heaters placed on the condenser plate is chosen such that it delivers app. 3 Watt to look after the heat leak to the condenser plate. The heaters chosen have the following specifications:

- $R_{\text{foil}} = 7.3 \text{ Ohms}$
- $R_{\text{LL}} = 41.7 \text{ Ohms}$
- $R_{\text{tot}} = 49.0 \text{ Ohms}$
- $I_{\text{nom}} = 28/49 = 0.57 \text{ Ampere (@ 28.0 Volts)}$
- $P_{\text{con_nom}} = 0.57^2 * 7.3 = 2.38 \text{ Watt}$
- $P_{\text{LL_nom}} = 0.57^2 * 41.7 = 13.61 \text{ Watt (13.61/14 = 0.97 Watt per liquid line)}$
- $I_{\text{max}} = 29.5/49 = 0.60 \text{ Ampere (@ 29.5 Volts)}$
- $P_{\text{con_max}} = 0.60^2 * 7.3 = 2.65 \text{ Watt}$
- $P_{\text{LL_max}} = 0.60^2 * 41.7 = 15.11 \text{ Watt (15.11/14 = 1.07 Watt per heater)}$

The selected elements for the liquid lines are the **ZUZ/15/4-336-4/HcAc** wire heaters of THERMOCOAX (www.thermocoax.com). This is a single core heater with cold ends. The wire chosen has a sheath metal of stainless steel. The ZUZ/HcAc wires have a line resistance per unit length of **12.4 ohms/m**.

These specifications are summarised in the following table:

	Liquid line heater (Wire)
Coating material	Stainless steel
Diameter	1.5 mm
Length cold/hot/cold	40 mm/3360mm/40mm
Resistance	41.7 Ohm
Power supply	28 Volt
Total Power nominal (approx)	13.61 Watt
Max Power density (@29.5V)	4.49 W/m
Connector type	CB05SPE/CEMENT8
Lead AWG	AWG 22

Table 3-1: Liquid line heater mechanical specifications

This wire heater is within the max power density requirement of 65.5 Watt/m.



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The foil heater is chosen such that it has app. the dimensions: 1.5 cm width and 4.0 cm length. The foil heaters should deliver app. 3-4 Watt when placed in series with the parallel liquid line heaters as presented in the previous section. This resulted in the following Minco foil heater.

	Condenser plate heater
Heater Number	Minco Foil HK 5222
Length	58.4 * 10.7 mm
Resistance	7.3 Ohm
Nom Power supply	28 Volt
Nom Power (approx)	2.38 Watt
Max Power Density (@29.5V)	0.42 Watt/cm ²
Lead AWG	26
Connector type	I
Adhesive	Minco #15 Epoxy

Table 3-2: Condenser foil heater specifications

This foil heater is below the max power density requirement of 0.465 Watt/cm².



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4 TTCS liquid line health heaters design rationale

The sizing of wire liquid line heaters is based on the trade off between:

- Get a reasonable heating rate of the capillary liquid lines in cold conditions.
- Avoid that the maximum temperature of the carbon fibre rods (to which the condenser tubes are attached) exceeds +100 °C.

For this reason two thermostats per branch are located on the two brackets to which the condensers are attached.

The required branch heater power to heat up the condenser lines is estimated on 11 Watt.

The sizing of the Minco foil heaters attached on the condenser plate is based on the estimated heat leak from the liquid lines to the condenser plate. The objective of the heater is to compensate the heat leak from the condenser lines to the condenser base plate. The required foil heater power is estimated on 3 Watt. In section 5 the worst calculations of the maximum temperature of the tubes, heaters and MLI is presented.

4.1.1 TTCS Liquid line heater safety and operational health measures

Non-operational and safety measures

In order to avoid overheating the carbon fibre rods (<+100 °C) the liquid line health heaters are equipped with 2 TS per heater line (Opening +54 °C/Closing +32 °C). The thermostats are located on the condenser line brackets as shown in Figure 3-13 and Figure 3-14.

This safety measure keeps the Tracker rods below 100 °C as is presented in the TTCS Safety approach RD-2 .

Operational health measures

In order to avoid the condenser inlet lines temperatures rise above set-point and critical temperatures the heaters are controlled by Pt1000's (Pt6aP, Pt7aP, Pt9aP, Pt10aP, Pt6aS, Pt7aS, Pt9aS, Pt10aS) during operation. The TTCE switches off the heaters above -20 °C. The location of these Pt1000 is shown in Figure 4-1 and Figure 4-2.



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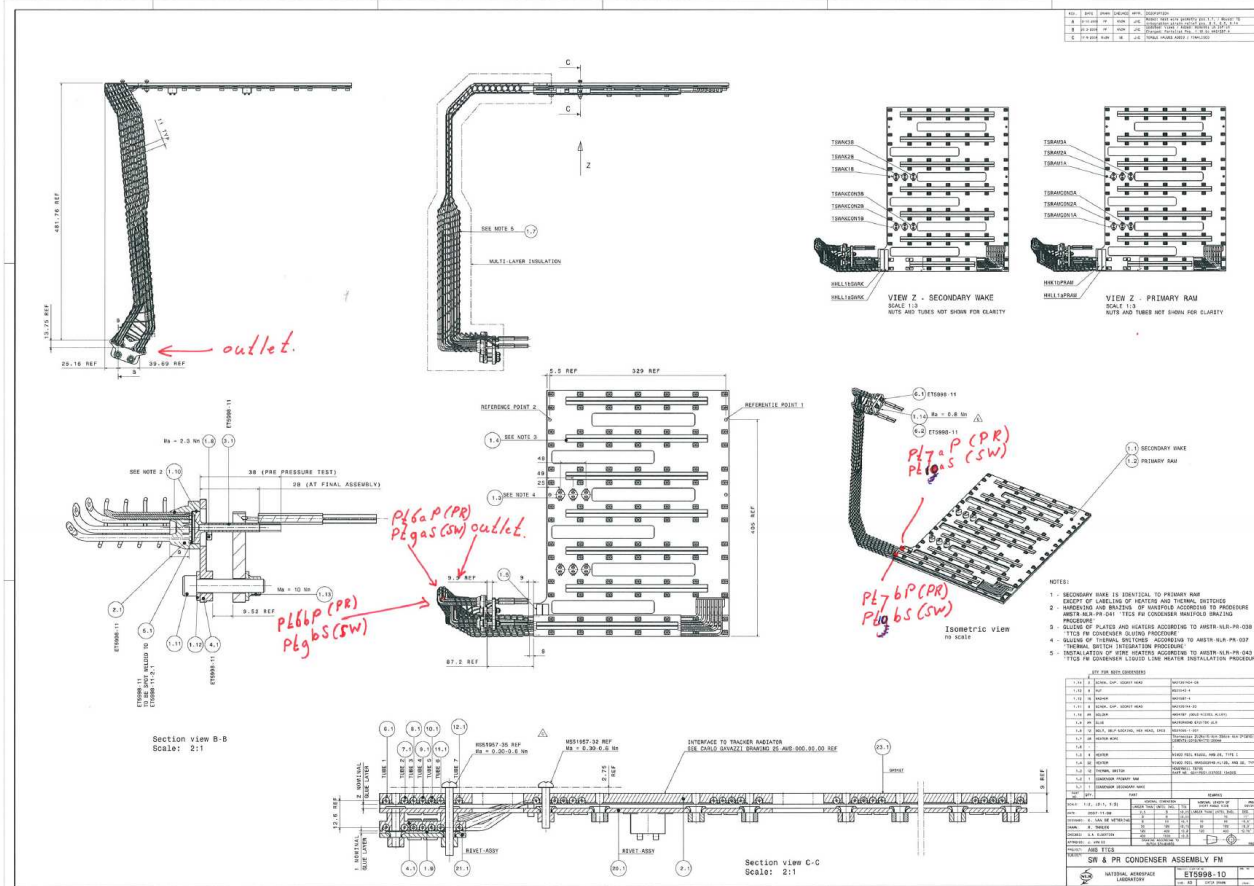


Figure 4-1: Pt1000 locations for health heater control during normal operation (Primary RAM/Secondary Wake)



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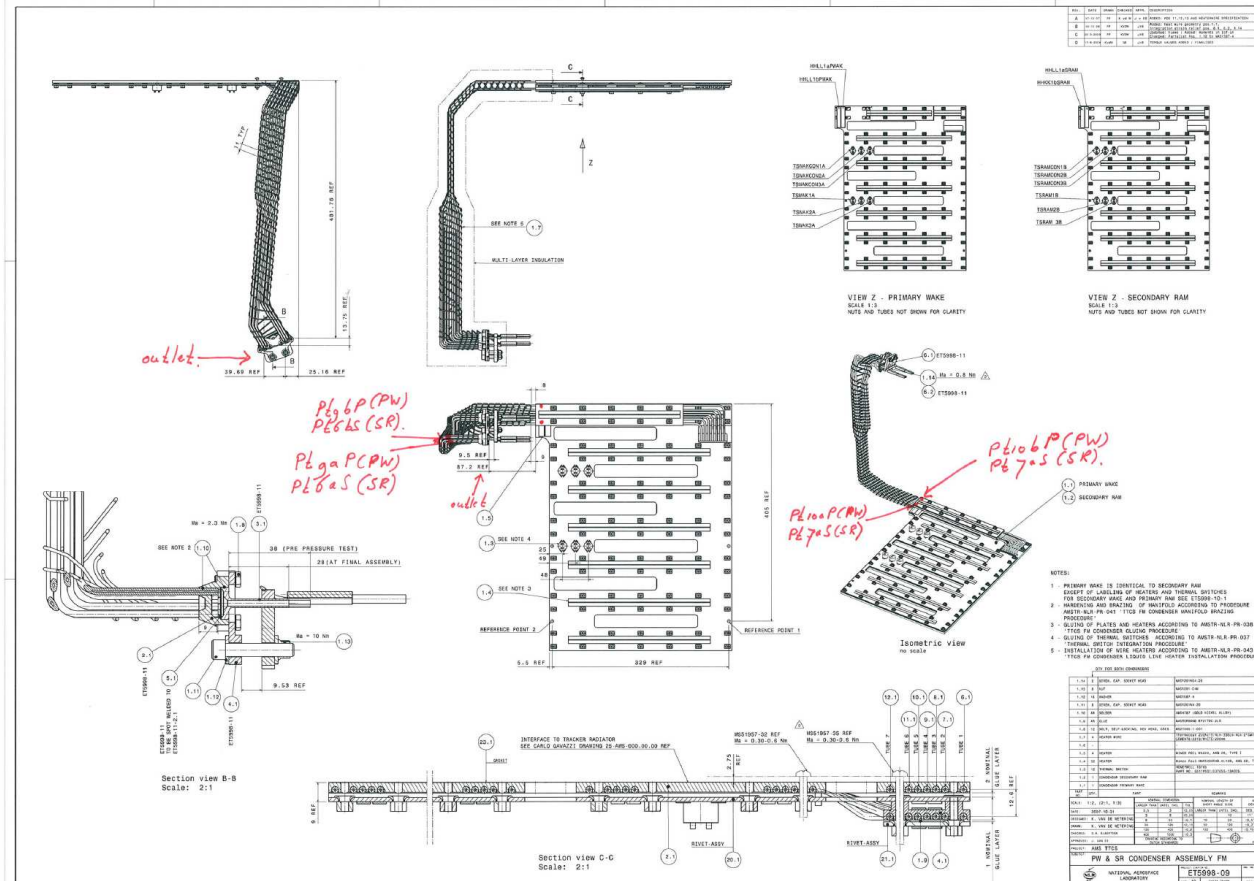


Figure 4-2: Pt1000 locations for health heater control during normal operation (Secondary RAM/ Primary Wake)



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5 TTCS liquid line health heaters design calculations

5.1 Thermal models

In order to estimate the maximum temperature of the carbon fibre rod, TTCS tubes and MLI calculations are performed

5.2 Failure case modelled

Preliminary calculations showed thermostats are needed and implemented on the bracket connections between the condenser and the carbon fibre rod.

Each heater circuit contains two thermostats. One in the feed line and one in the return line.

Worst case failure case

- Two thermostats in one circuit do not function well meaning one heater can still be switched on continuously
 - Power 13.6 W on heater wire (this is called half power in the SINDA model)
 - Effective radiative environment temperature for ROD and tubes MLI 30 °C

5.3 Thermal Models

Two models are used.

1. SINDA model to calculate the rod, tube and MLI temperatures
2. ThermXL (ESATAN) model to estimate the maximum wire heater temperature

5.4 SINDA Model

Modelled is:

- Carbon Fibre rod
- MLI wrapped around carbon fibre rod
- Brackets connecting the condenser tubes to the carbon fibre rod
 - modelled as arithmetic nodes
- MLI around tubes and heaters
- Heater power is directly dissipated in/on the tubes
-

5.4.1 SINDA Model results

First model results with:

$$\epsilon_{\text{MLI tubes}} = 0.05$$

$$\epsilon_{\text{tubes}} = 0.20$$

$$\epsilon_{\text{MLI Rod}} = 0.05 \text{ (TBC by Serena Borsini)}$$



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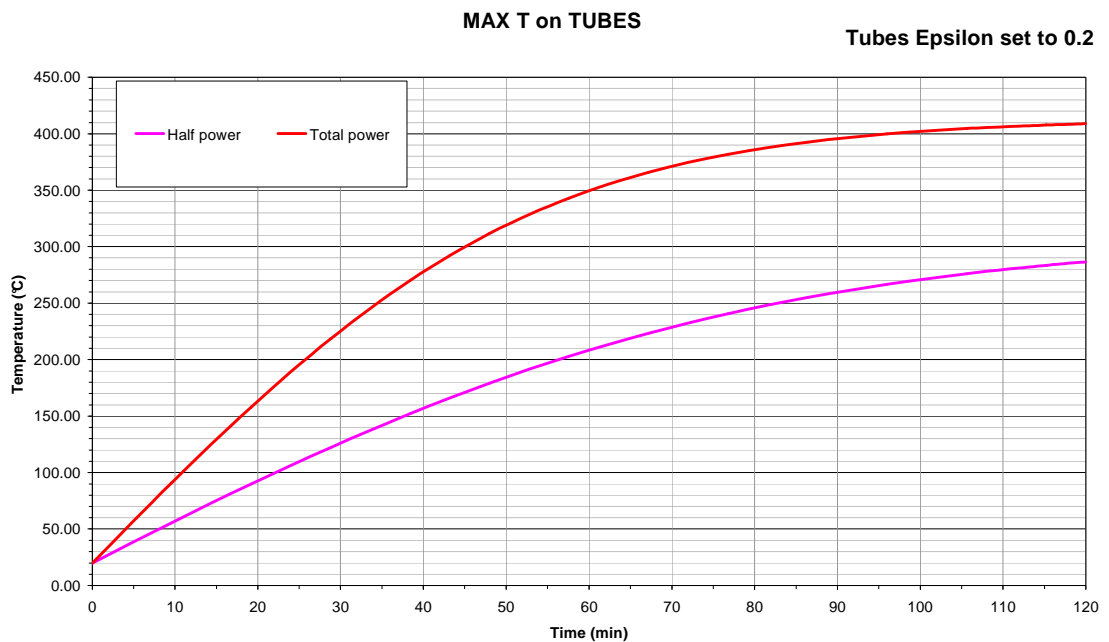


Figure 5-1: Maximum temperature on tubes (heating directly on tubing)

Maximum tube temperature is approximately 300 C. In practice the heat will be dissipated in the wire heater radiated to the tubes resulting in much lower temperature on the tubes itself.

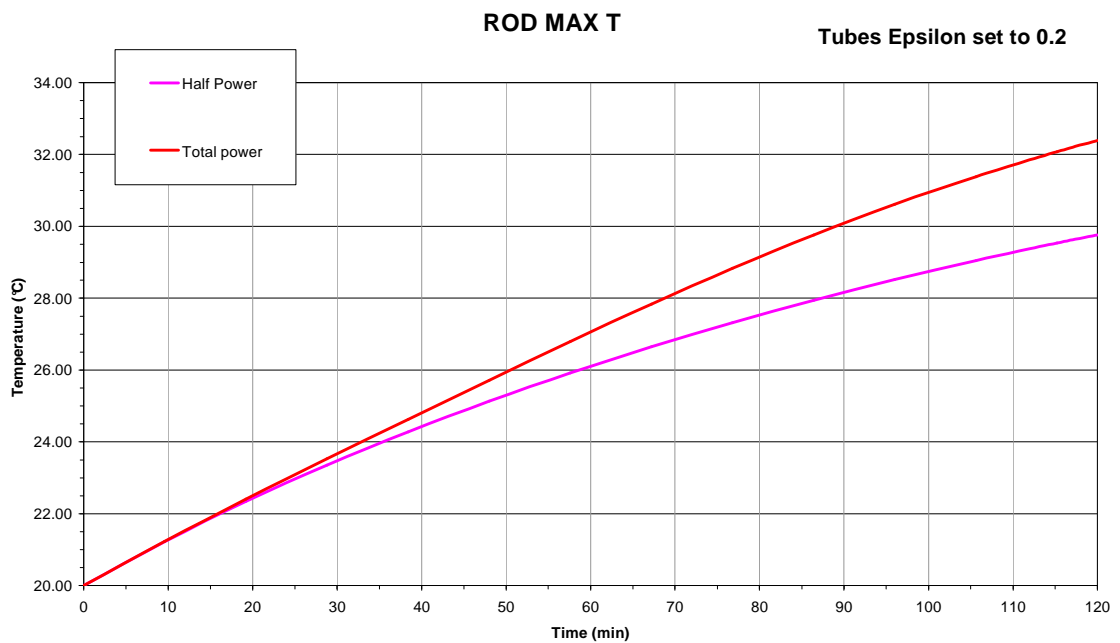


Figure 5-2: Maximum rod temperature



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As the rod tubes are wrapped in MLI and the rods in separate MLI the heat transfer to the rod is mainly through the brackets. The maximum temperature of the rod near the bracket is shown.

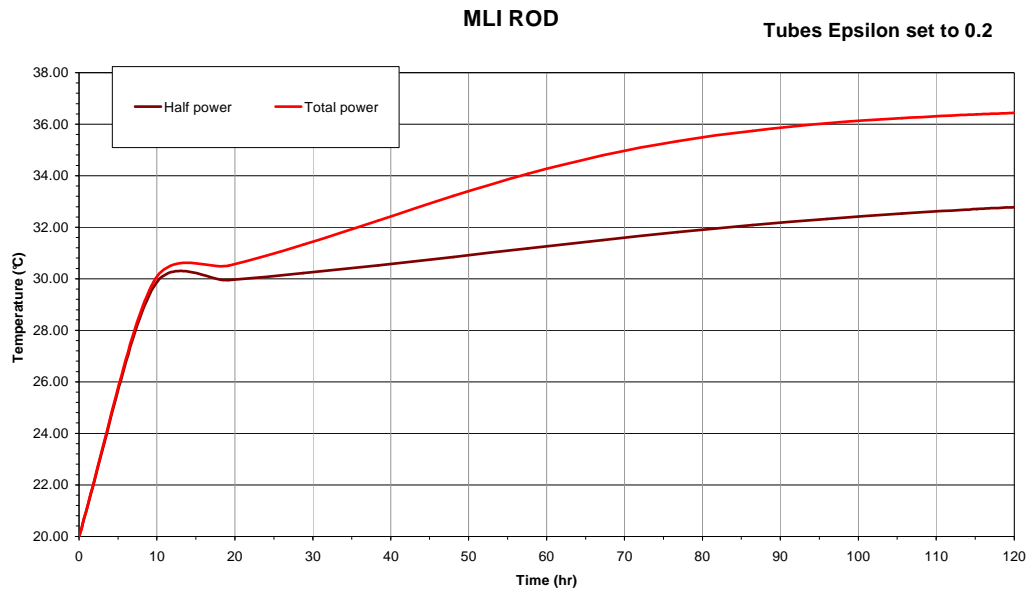


Figure 5-3: Rod MLI temperature

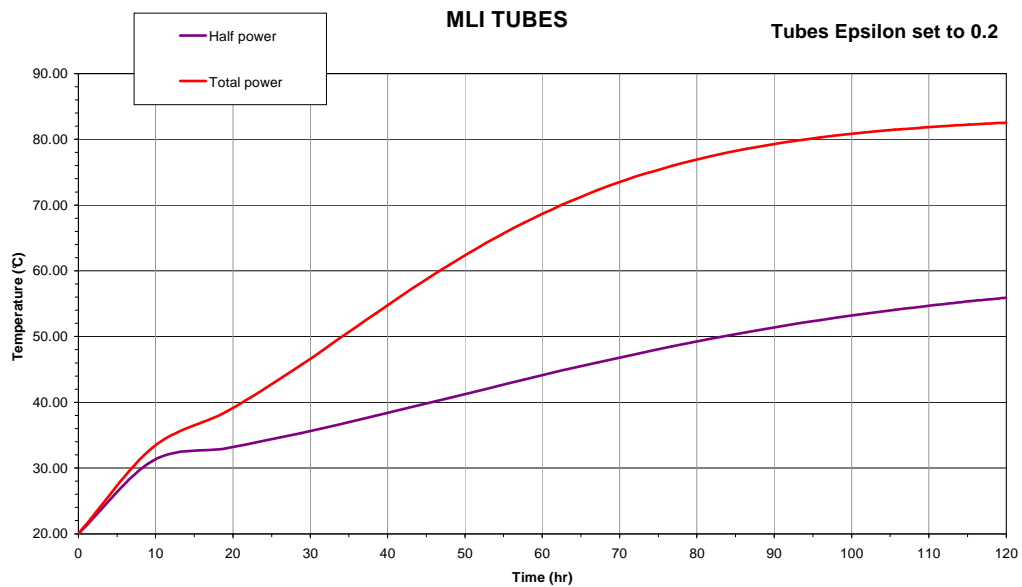


Figure 5-4: Tube MLI temperature

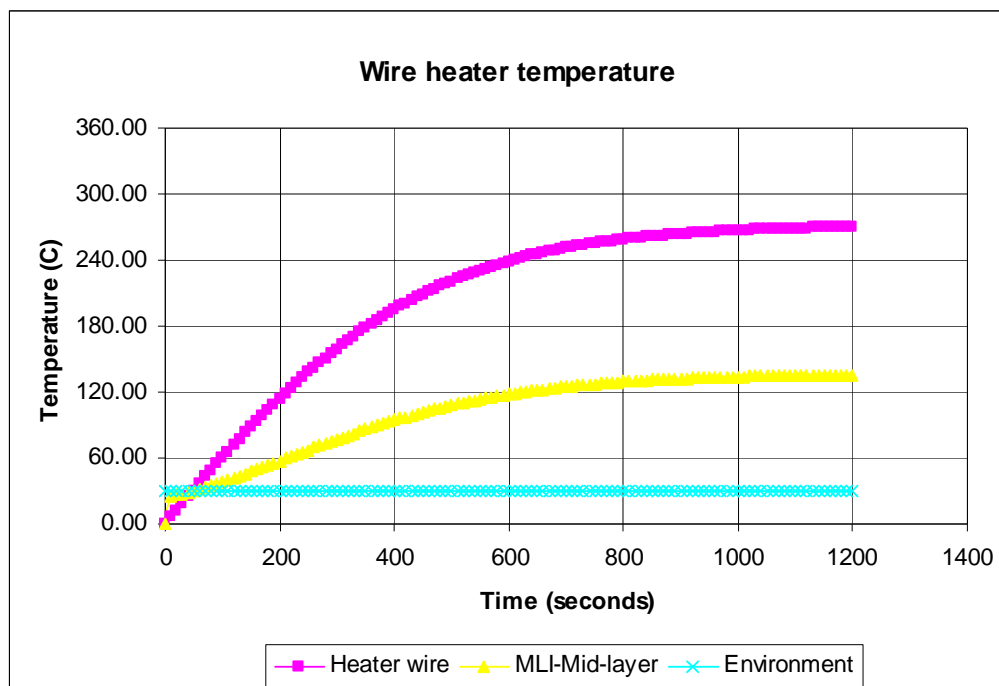
5.4.2 Conclusions Sinda Model

The rod heating is mainly by conduction through the bracket and very slow. This indicates that all thermostats on the bracket will be switched before the rod reached 100 C. The rods are safe. The tube maximum temperature is not realistic in this model as the heat is directly dissipated in the tubes.

5.5 ThermXL model

This is a simple 3 node model estimating the maximum wire heater temperature. This is needed to check the kapton based MLI is not overheated by touching the heater wire.

- Node 1: Stainless steel wire heater dissipating 13.6 W
 - Length wire heater 3.36 m, d= 1.5 mm, material stainless steel $\rho = 890 \text{ kg/m}^3$, Mass 0.049 kg, $C_p = 460 \text{ J/kgK}$
 - $\epsilon_{\text{tubes}} = 0.25$ (stainless steel)
- Node 2: MLI wrapped around the tubes and heaters
 - $A = 0.121 \text{ m}^2$ (d =50 mm, L = 0.77 m)
 - $\epsilon_{\text{MLI tubes}} = 0.10$ (realistic MLI value)
- Node 9999: Environment boundary temperature at 30 °C.



Figuur 5-5: Temperature wire heater



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5.5.1 Conclusions ThermXL model

It is shown that the expected maximum temperature of the wire heater with a realistic IR emission coefficients for both the wire and the MLI is approximately 270 C.

This maximum temperature could be used as extreme worst case estimation for the tube temperature at locations where the wire heater touches the tubes. It falls well within the 300 C MDP safety temperature level for heated parts as used in the MDP analyses of the TTCS Safety approach AMSTR-NLR-TN-044.

5.6 Conclusions

Based on the presented results the MLI temperature specification for is set to +290 C and the Thermostat design is implemented. A test is proposed to verify the heating rate of the tubing.



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